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PELLETIZING OF IRON ORE BY PARTIAL OR FULL SUBSTITUTION OF BENTONITE BY ORGANIC BINDERS

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PELLETIZING OF IRON ORE BY PARTIAL OR FULL SUBSTITUTION OF BENTONITE BY ORGANIC BINDERS

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ABSTRACT

Results of a study conducted to determine the properties of iron ore pellets made from Mount Wright and Carol Lake ore concentrate fines with partial and full substitution of bentonite by several organic binders are presented. Carboxy methyl celluloses 7H and 6CTL, hydroxy ethyl cellulose (natrosol) and modified guar gum all produce pellets of acceptable wet, green and dry strength. However, when fully substituted, an inorganic binder such as calcium carbonate is required for satisfactory strength development after induration. Also, the Carol Lake ore requires an oxidation step prior to the pelletization process for obtaining acceptable strength on induration. Mixing the Carol Lake ore with the Mount Wright ore in a 50-50 ratio also achieves the same result. The failure of the Carol Lake ore in the pelletization process is attributed to the low hematite content of the ore. These results are very similar to those from the extrusion studies carried out earlier.

Keywords: Iron ore agglomeration, iron ore pellets, organic binders for iron ore.

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BOULETAGE DU MINERAI DE FER PAR REMPLACEMENT PARTIEL OU TOTAL DU BENTONITE PAR DES LIANTS ORGANIQUES

par

A.K. Kuriakose et D.H.H. Quon

RÉSUMÉ

Le présent rapport expose les résultats d'une étude en vue de déterminer les propriétés des boulettes de minerai de fer faites à partir de fines de concentré de minerai de Mount Wright et de Carol Lake en remplaçant partiellement ou totalement le bentonite par plusieurs liants organiques. Les carboxyméthylcelluloses 7H et 6CTL, l'hydroxyéthylcellulose (natrosol) et la gomme de guar modifiée ont toutes produit des boulettes dont la résistance en cru, la résistance en condition mouillée et la résistance à sec étaient acceptables. Toutefois, lorsque le bentonite est entièrement remplacé, un liant inorganique tel que le carbonate de calcium est nécessaire pour procurer une résistance satisfaisante après le durcissement. De plus, le minerai de Carol Lake exige une oxydation avant le procédé de bouletage pour obtenir une résistance acceptable lors de l'endurcissement. Le fait de mélanger le minerai de Carol Lake avec celui de Mount Wright selon un rapport 50-50 donne les mêmes résultats. La rupture du minerai de Carol Lake lors du procédé de bouletage est imputable à la faible teneur en hématite dans le minerai. Ces résultats ressemblent beaucoup à ceux obtenus lors d'études d'extrusion réalisées antérieurement.

MOTS-CLÉS : agglomération du minerai de fer, boulettes de minerai de fer, liants organiques pour le minerai de fer.

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INTRODUCTION

It is common practice in the iron ore industry to pelletize and indurate iron ore concentrates and fines before they are shipped to iron and steel producers. Traditionally, bentonite is used as a binder in the pelletizing process. Aside from its primary purpose which is to cause the concentrate particles to adhere together thus creating a pellet, a good binder must be able to increase the strength of the material in order to minimize the degradation of the green, dry and indurated pellets during storage, transportation and processing. Presently, some iron ore companies are exploring the possibility of utilizing alternate binders in place of bentonite to reduce the level of impurity introduced into the ore by the bentonite, and also to improve the reducibility of the pellets in the blast furnace (1,2). Organic and inorganic binders have been used extensively in ceramic processing but these have not been examined thoroughly as binders for iron ore agglomeration (3-6). However, it has been demonstrated that certain organic polymers can be used as plasticizers and binders for iron ore extrusion (7,8).

A cellulose based organic binder (Peridur XC-3*) has been successfully used for the agglomeration and pelletizing of Brazilian iron ore (9-12). Pilot-plant tests conducted in Cia Vale Do Rio Doc (CVRD) using peridur binder reportedly produced fired pellets of acceptable physical characteristics as specified by the ISO standard (13). However, it has also been reported by others that similar binders are not suitable for the agglomeration of Canadian iron ore because of differences in the physical characteristics of the ore (9).

The purpose of this work is to examine the suitability of a variety of organic binders for the agglomeration/pelletizing of Canadian iron ore by the balling technique.

GENERAL CHARACTERISTICS OF BINDERS

Binders can be, in general, classified into two distinct groups - (1) those which modify the physical characteristics of the pellets and (2) those which modify the chemical characteristics of the pellets. Organic binders

such as the cellulose derivatives belong to category 1; they do not react with iron ore, but generally bond (glue) the ore particles at low temperature. Binders in category 2 such as calcia and magnesia tend to react with the iron ore at high temperature with the formation of a liquid phase and bridge the grains at the grain boundary, providing high temperature strength.

In ceramic processing, organic binders have been used to provide green strength and to enable the materials to be molded into desirable shapes before firing, by techniques such as dry pressing, extrusion, tape casting, injection molding and compression molding. Both physical and chemical characteristics of these binders have been well documented in the literature (3-6) and they have been classified based on their origin, chemical composition, physical characteristics, molecular weight, polarity, affinity for water, and dominant adhesion mechanisms.

The suitability of the various binders that can be used for iron ore agglomeration is determined by the requirement that the binder be readily soluble or dispersable in a liquid (either organic or water) and does not contaminate iron ore. The uniform dispersion of the binder in the particulates is very important for the development of good green strength. The liquid phase in which the binder is dissolved can be driven off from the green product by evaporation. The binder is retained in the product providing organic bridges between particles.

EXPERIMENTAL

RAW MATERIALS

Iron Ore Concentrates

The iron ore concentrates used for the balling experiments were the Mt. Wright and Carol Lake varieties. A noticeable difference between these concentrates is in their magnetite content; the Carol Lake ore has a significantly higher magnetite content than the Mt. Wright ore. The accessory minerals in both ores are similar - small amounts of quartz and feldspar and traces of compounds of manganese, calcium and similar elements - as identified by X-ray diffraction and chemical analysis.

Most of the investigation was carried out using the Carol Lake ore. A few experiments were performed on Mt. Wright ore and Mt. Wright-Carol Lake ore mixtures.

Binders

Two different approaches were used to determine the effect of adding organic binders on the physical characteristics of the iron ore pellets. In one, a partial substitution of Greek bentonite by sodium alginate or methyl cellulose (MC) was studied and in the second, the bentonite was totally substituted by organic binders. Four types of organic binders were investigated in the latter study - carboxyl methyl celluloses of different viscosities, hydroxyl ethyl cellulose (natrosol) and modified guar gum. In some cases where bentonite was not one of the ingredients, a small amount of calcium carbonate was also included in the mixture in order to enhance the strength of the pellets on induration. The amounts of binder added to the ore concentrate are given in Table 1.

BATCH PREPARATION AND TESTING

The mix composition used for the balling was made up of a 2 kg batch. After weighing the individual components, they were mixed in a blender until a homogenous mixture was obtained. Agglomeration of the concentrates into pellets was conducted in an airplane tire pelletizer. Seed balls were prepared by sprinkling the dry mix with water while the tire was being rotated. The seeds were then allowed to grow to a desirable size and finally screened to -12.5 + 11.2 mm (-1/2" + 7/16") size. The balls were then subjected to a drop test, and wet and dry strength measurements. Five balls were used for each test and the results were averaged.

After oven-drying the green pellets at 125°C, they were indurated in a resistively heated electric furnace. Attempts were made to simulate, as closely as possible the induration conditions of the industrial process, subject to the limitations of the available furnace. The bulk of the experimental work was conducted in determining the effect of variables such as temperature and time of induration on the crushing strength of the pellets. The oven-dry pellets (placed in an alumina boat) were introduced initially in the cooler zone of the furnace to allow the organic binder to

burn-off. After the decomposition of the binder, they were introduced rapidly into the hot zone for final induration. The time of heating of the pellets from room temperature to the test temperature was usually less than 10 minutes. The pellets were heat-treated at temperatures from 500 to 1300°C for a period of 10 to 20 minutes. On completion of the induration cycle, the pellets were removed from the hot zone and cooled in a fiber insulated refractory crucible to prevent thermal shock of the pellets due to the rapid cooling. After the pellets were cooled to room temperature, crush-strength tests were conducted.

RESULTS AND DISCUSSION

STRENGHT OF THE PELLETS BEFORE INDURATION

The acceptable standards for these pellets require a minimum drop number value of 5, a wet strength of 9N and a dry strength of 44N before induration.

A. Partial Substitution of the Bentonite by Polymer

The results obtained for the pellets made by the partial substitution of the bentonite by organic binder are presented in Table I. For the sake of comparison, the corresponding results for pellets made with bentonite only are also shown in the same Table. The results show a low drop number and low dry strength for pellets containing 0.6% bentonite only and also for pellets with 0.3% bentonite and 0.1% MC. Higher drop number and dry strength are developed in pellets containing the higher amounts of organic binder. There is no apparent difference in the dry strength for pellets containing either alginate or MC at the same level of addition.

B. Full Substitution of the Bentonite by Polymer

The physical properties of the green pellets containing varying amounts of polymers, instead of bentonite, as binder are plotted in Fig. 1 to 3. Figure 1 shows that the drop number increases as the binder concentration is increased up to at least 0.3 wt %. Carboxyl methyl cellulose develops an acceptable drop number at as low a binder concentration as 0.1 wt % and this drop number is higher than that of the pellets containing even higher

amounts of modified guar gum and natrosol.

Fig. 2 which is a plot of the wet strength versus binder concentration shows that a wet strength of at least 13N is developed in all these cases. The wet strength generally decreases with increasing binder concentration except for pellets containing the carboxyl methyl celulose (6CTL). In this latter case the wet strength increases initially with increasing binder concentration to 0.3 wt % and then decreases as the binder concentration is increased further. This behaviour is attributed to the plasticizing effects of the respective polymers.

The dry strength development of the pellets bonded with organic polymer is illustrated in Fig. 3. The strength generally increases with increasing binder concentration. Pellets made from all the compositions have dry strength considerably higher than the required 44N.

BEHAVIOUR OF THE VARIOUS COMPOSITIONS ON INDURATION

Results of strength measurements on pellets fabricated using various binders and binder combinations after induration are presented in Table II and illustrated in Fig. 4 to 9. A discussion of these results follows.

A. Pellets Bonded With Bentonite Only, Polymer Only and With Bentonite-Polymer Mixture, Using Carol Lake Ore

The strength development of pellets of Carol Lake ore made with the addition of bentonite only, polymer only and also a bentonite-polymer mixture after induration at 1050, 1150, 1250 and 1300°C for 20 minutes is shown in Fig. 4. It is clear that the indurated strength increases with induration temperature. As can be seen from Table II, the strength increases with increasing induration time also. The maximum strength after induration at 1300°C is only 1620N for the pellets containing 0.6% bentonite and 800N for pellets containing organic binder alone. These values are considerably below the ISO strength requirement of 2000N. As was observed in an earlier study on the production of iron ore pellets by extrusion (3,4), the pellets containing bentonite only develop a higher indurated strength than those containing organic binders only. This is also observed after balling.

B. The Effect of Calcium Carbonate Addition in the Absence of Bentonite

Fig. 5 illustrates the effect of adding 1% by weight of calcium carbonate to the pelletizing mix of organic binders only on Carol Lake ore, Mt. Wright ore and 50-50 Carol Lake/Mt. Wright ore mixture. Although the strength of the Carol Lake ore pellets increases with the addition of calcium carbonate, it still does not have acceptable strength; the Mt. Wright ore produces pellets with more than acceptable strength and the 50-50 mixture of the two ores also produces pellets of satisfactory strength. The strength improvement of the pellets containing 1 wt % calcium carbonate on induration is attributed to the formation of slag and/or calcium ferrite bonds in the pellets resulting from the reaction of oxides of calcium, iron and silicon.

A considerable difference in the indurated strength is seen for pellets fabricated from Carol Lake and Mt. Wright ores. This phenomenon has been reported previously in the work dealing with pellets formed by the extrusion technique (3,4). To improve the crush strength of Carol Lake ore, the ore concentrate had to be roasted at 800°C to allow the oxidation of the magnetite to hematite. The extruded pellets formed by the oxidized ore developed a crush strength comparable to that of the pellets fabricated from the Mt. Wright ore. The strength improvement is due principally to a higher reactivity of ferric oxide than magnetite with the calcium oxide to form calcium ferrites and a slag phase, thus forming stronger bonds (13).

In this work, an attempt was made to increase the ferric oxide content of the Carol Lake ore by blending it with Mt. Wright concentrates on a 50-50 wt % basis, so that the formation of a slag phase and calcium ferrites was promoted by the higher hematite content. This was successful as can readily be seen from Fig. 5. The indurated strength of the mixed ore pellets exceeded the ISO strength requirement (14).

THE EFFECT OF VARIOUS ORGANIC BINDERS TOGETHER WITH CALCIUM CARBONATE ON THE INDURATION-STRENGTH OF PELLETS

Mt. Wright iron ore concentrate fines were used for these studies. Based on differential thermal analysis (DTA), the organic binders undergo decomposition and oxidation at about 500°C (7). Due to the loss of binder, a weakening of the pellets is anticipated around this temperature and the

strength will not recover until the pellets are indurated at a high temperature. For this reason, in the present study, prior to the induration process at high temperature, the dry pellets were first heat-treated at 500°C to allow the binder to burn-off and the strength of the resulting pellets was determined. Induration at higher temperatures was subsequently carried out on these oxidized samples in order that the strength recovery could be followed. The results of these experiments are illustrated in Fig. 6 to 9.

It is clear that there is substantial decrease of strength occurring in the pellets after the binder burn-off at 500°C. However, induration at 1050°C restores the strength of the pellets to beyond the original value, except in the case of guar gum. A strength of 2000N is readily achieved by induration at 1250 or 1300°C for 20 minutes for pellets made with each of the organic binders studied at 0.1% level. Increase of binder concentration beyond 0.1 wt % is not avantageous in most cases. Thus, a combination of 0.1 wt % of any of the organic binders investigated in the present study with 1 wt % calcium carbonate is satisfactory as a substitute for bentonite in the pelletization of Mt. Wright iron ore concentrate fines.

CONCLUSIONS

The conclusions of this study are very similar to those reached in the extrusion-induration studies performed earlier. The organic materials, carboxy methyl celluloses 7H and 6CTL, hydroxy ethyl cellulose (natrosol) and modified guar gum all produce iron ore pellets of acceptable wet, green and dry strength when substituted for bentonite in the agglomeration process. The bentonite substitution can be either partial or full. When fully substituted, however, these pellets require an additional inorganic binder in order to provide satisfactory strength after induration. Calcium carbonate is a suitable inorganic binder for this purpose.

Mt. Wright iron ore concentrate fines produce pellets with compressive strengths greater than 2000N when made with the addition of 0.1% of any of the above organic binders and 1 wt % calcium carbonate at an induration temperature of 1250 and 1300°C. Under the same conditions, however, Carol Lake ore fines do not produce pellets of acceptable indurated strength. A

50-50 mixture of the two ores, nevertheless, produces pellets of satisfactory strength.

The reason for the failure of the Carol Lake ore is its lower hematite, content. The reaction between hematite, calcium oxide and silica to form calcium ferrites and slag is a very important step in the induration of the iron ore pellets when calcium carbonate is used as an inorganic binder. Blending the Carol Lake ore with the Mt. Wright ore yields a mixture that has a sufficiently high concentration of hematite.

A major advantage in using organic binders for balling is the pellet's increased dry strength.

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Table 1 - Strength Development of the Pellets

Bentonite %	Alginate %	MC %	$CaCO_3$ %	Drop Number	Dry Strength (N)	Strength at 500°C (N)
0.6				2	20	59
	0.3			11	108	39
	0.3		1.0	6	59	23
		0.3		12	118	39
0.3		0.1		3	29	39
		0.3	1.0	6	59	23
		0.3*	1.0	11	108	20
		0.3+	1.0	13	127	20

* pellets were prepared with Mt. Wright concentrate.
+ pellets were prepared with a 50-50% concentrate mixture of Mt. Wright and Carol Lake ores.

Table 2 - Indurated Strength of Pellets at Various Temperatures

Exp.	Extrusion Mix	Indurated Temp. C	Time min.	Strength N	Time min	Strength N
1	0.6% Greek bentonite	1300	10	1436	20	1620
		1250	10	750	20	1416
		1150	10	520	20	784
		1050	10	216	20	477
2	0.3% alginate	1300	10	549	20	750
		1250	10	490	20	722
		1150	10	248	20	405
		1050	10	147	20	209
3	0.3% MC	1300	10	428	20	770
		1250	10	379	20	594
		1150	10	196	20	500
		1050	10	98	20	180
4	0.1% MC	1300	10	1137	20	1375
	0.3% Greek	1250	10	856	20	1264
	bentonite	1150	10	549	20	863
		1050	10	196	20	294
5	0.3% MC	1300	10	1117	20	1960
	1% $CaCO_3$	1250	10	869	20	1744
		1150	10	294	20	539
		1050	10	134	20	255
6	0.3% alginate	1300	10	1947	20	2081
	1% $CaCO_3$	1250	10	1774	20	2009
		1150	10	533	20	852
		1050	10	242	20	343
7	0.3% MC*	1300	10	2193	20	2921
	1% $CaCO_3$	1250	10	2080	20	2525
		1150	10	552	20	944
		1050	10	124	20	186
8	0.3% MC+	1300	10	1741	20	2640
	1% $CaCO_3$	1250	10	2036	20	2653
		1150	10	490	20	1039
		1050	10	265	20	340

* Pellets were prepared with Mt. Wright iron ore concentrate.
\+ Pellets were prepared by mixing 50% Mt. Wright and 50% Carol Lake iron ore concentrates.

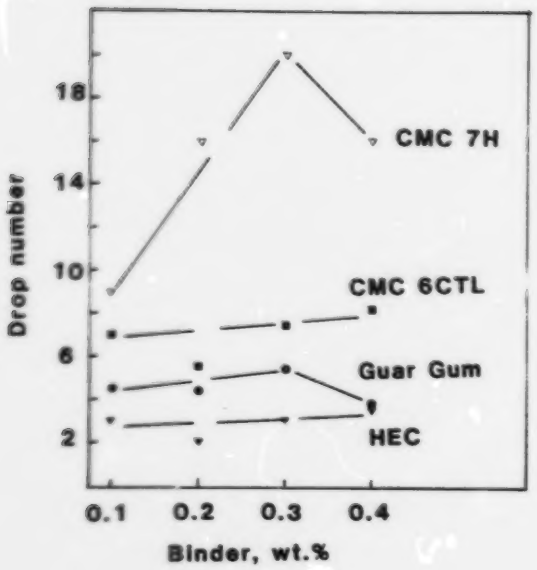

Fig. 1. Drop number versus binder concentration of the green pellets

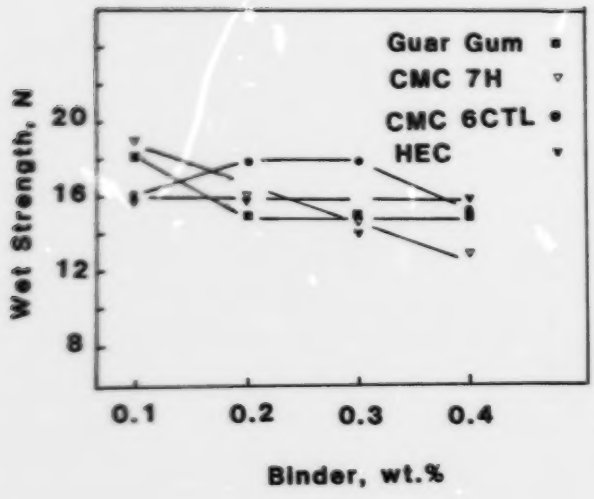

Fig. 2. Wet strength versus binder concentration of the green pellets

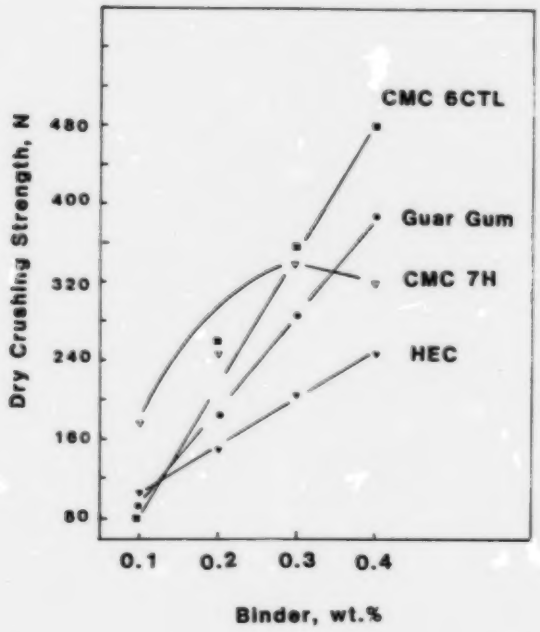

Fig. 3. Dry strength versus binder concentration of the green pellets

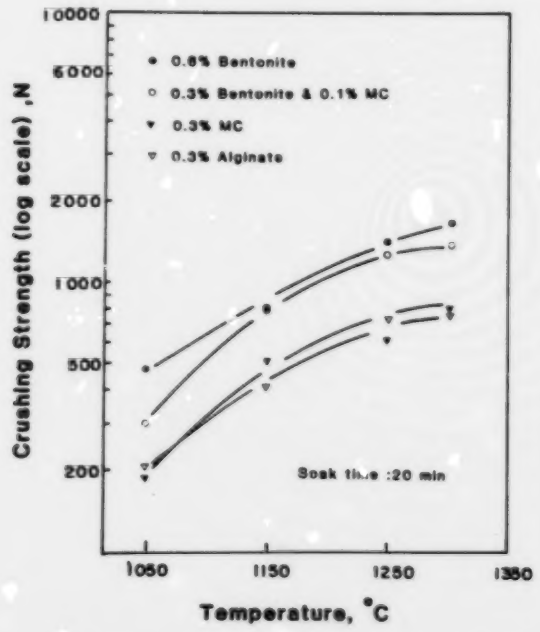

Fig. 4. Strength development of the Carol Lake pellets indurated at different temperatures for 20 min.

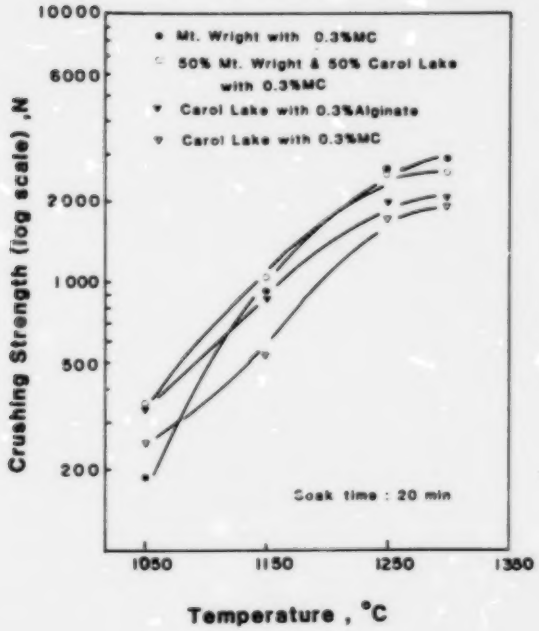

Fig. 5. Strength development of the pellets containing organic binders and mixture of Carol Lake and Mt. Wright ores indurated at different temperatures for 20 min.

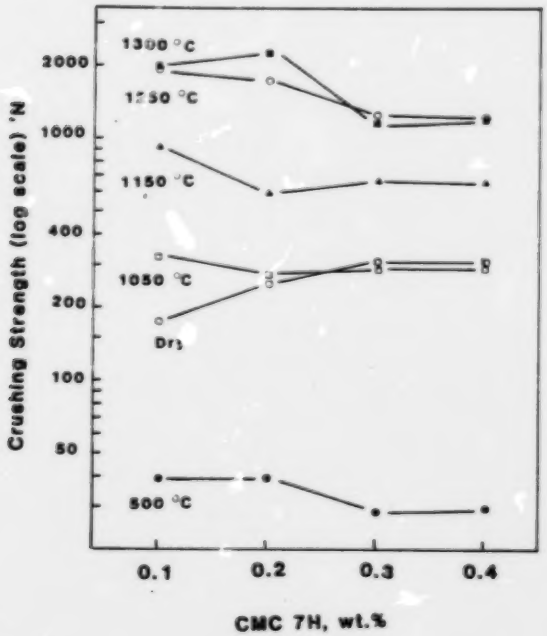

Fig. 6. Strength development of the pellets containing variable amounts of CMC-7H indurated at different temperatures for 20 min.

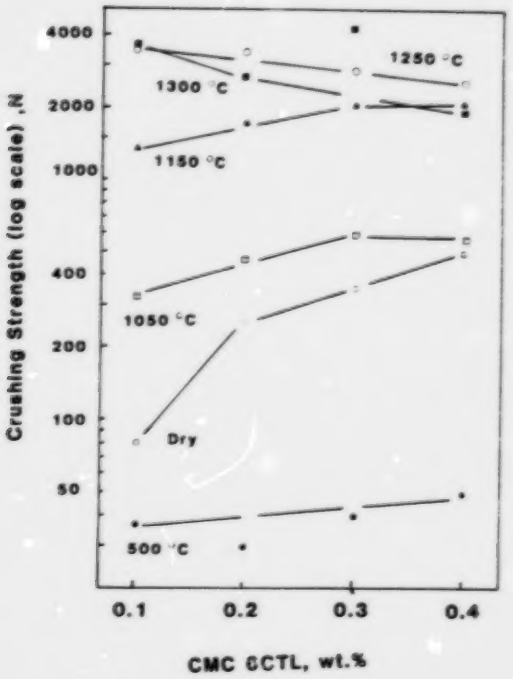

Fig. 7. Strength development of the pellets containing variable amounts of CMC-6CTL indurated at different temperatures for 20 min.

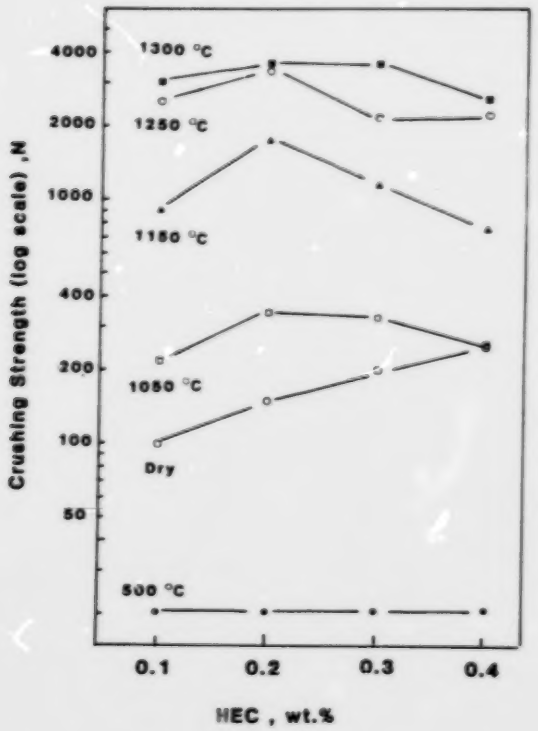

Fig. 8. Strength development of the pellets containing variable amounts of HEC (Natrosol) indurated at different temperatures for 20 min.

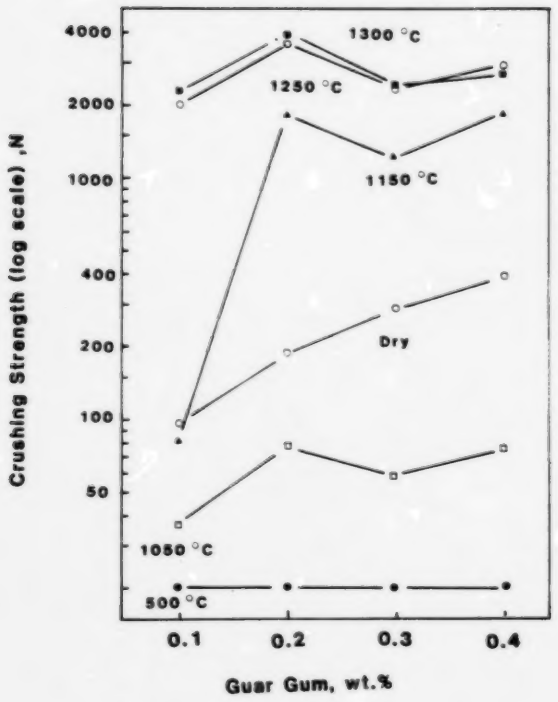

Fig. 9. Strength development of the pellets containing variable amounts of guar gum indurated at different temperatures for 20 min.